SIMULATED EFFECTS OF SEX RATIO DISPARITY ON POPULATION DYNAMICS OF THE ENDANGERED HOUSTON TOAD (*BUFO HOUSTONENSIS*)

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

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Amphibian populations have been documented to be declining worldwide for the last three decades. Determining the risk of extinction is one of the major goals of amphibian conservation. However, sex ratios are difficult to determine for amphibians with short, seasonal breeding cycles. The sex ratio of reproductively mature individuals within a population is an important determinant of population dynamics, particularly for species such as the Houston toad (*Bufo houstonensis*), an endangered species endemic to east central Texas. The species demonstrates differences in the age at sexual maturity for males and females thus causing a large sex ratio disparity. The objective of our research is to determine how this disparity affects the population dynamics and ultimately, the future of this critically endangered anuran. We conducted a thorough literature review to obtain the best basic demographic data available and developed a stage- and sex-structured population dynamics model for the Houston toad using STELLA®7.0.1. We then applied the model to estimate potential population growth rates under a variety of assumptions about the disparity in age at sexual maturity between males and females and the resulting sex ratio of reproductively mature individuals within the population. Finally, we evaluated the performance of the model based on published literature. Our results showed that the populations of Houston toad declined when the sex ratio (male: female) was around 4:1

and the populations exhibited stability when the sex ratio was around 1:1. We also determined that sex ratio disparity predominantly affects Houston toad populations that are already at low numbers, as sex ratio disparity intrinsically increases as juvenile survivorship increases.

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CHAPTER I

INTRODUCTION

The global amphibian crisis

Biodiversity and functioning of our biosphere are threatened as amphibians have been facing an alarming rate of decline and extinction that surpasses most other taxa (Blaustein et al., 2007) with at least 43% of anuran species facing decline (Stuart et al., 2004). One-third of extant amphibians possibly face extinction within the next 50 years due to a climbing projected extinction rate that is thousands of times greater than the current background extinction rate (Blaustein et al., 2007). This horrifying reality of biodiversity loss can be attributed to factors such as the skin disease chytridiomycosis (Johnson, 2006), invasive species (Kats et al., 2003), climatic change and wetland desiccation (McMenamin et al., 2008), environmental toxicants (Carey et al., 1995), and habitat loss (Gallant et al., 2007).

Amphibians play an important role in their ecosystems in part to their complex life cycles that allow them to occupy both aquatic and terrestrial habitats at different stages (Whiles et al., 2006) and as consumers that contribute to energy flow. Additionally, in some ecosystems they are the primary source of vertebrate biomass (Blaustein et al., 1994). Furthermore, their extinction could have even greater implications for various ecosystems since amphibians are thought to be an indicator species for environmental problems (Storfer, 2003). While habitat loss is a major player in the decline of amphibians (Gallant et al., 2007), it is imperative to look at aspects of their ecology that may be hindering the growth of endangered populations. Once an anuran species has gone extinct from a particular location it is often difficult for them to recolonize it (Blaustein

et al., 1994) which is a consequence of their "short distances, site fidelity, and physiological constraints" (Blaustein et al., 1994). Hence the need for conservation plans that also take ecological hindrances. Identifying potential reasons for hindrance in population growth or reasons for decline in small, fragmented amphibian populations could be important in determining what steps should be taken in their future conservation plans.

Houston toad ecology

The Houston toad (*Bufo houstonensis)* is the most critically endangered toad as well as the first federally endangered amphibian to be listed (Brown et al., 2013). It is endemic to nine counties found in east central Texas: Austin, Bastrop, Burleson, Colorado, Lavaca, Lee, Leon, Milam, and Robertson (Duarte et al., 2011).

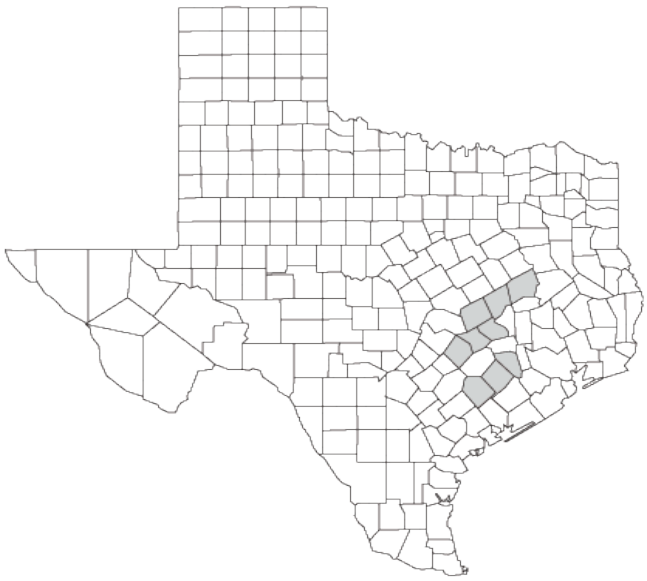

Figure 1. Map of Texas with the range of the Houston toad shaded in gray.

Their preferred habitat occurs in the Lost Pines ecoregion in Bastrop County, which is also where their largest subpopulation resides. This area consists of mixed pine-oak woodlands within a matrix of grasses (Swanack et al., 2009). Loblolly pines (*Pinus taeda*) are the most common pine within these woodlands. *Bufo houstonensis* prefers a sandy substrate in which they can burrow into. Other common daytime shelters for the species include leaf litter, rocks, logs, and sometimes burrows of small animals. They have been found to prefer formations of Sparta Sand, Weches, Queen City Sand, Reklaw, and Carrizo Sand (Forstner et al., 2004). This is supported by the presence of Carrizo Sand and Reklaw formations under 73% of the Griffith League Ranch habitat, where the largest subpopulation is found (Forstner et al., 2004).

Its reproductive ecology and breeding dynamics have been studied and reported in papers by Hillis et al, 1989 and Jacobson, 1989 respectively. It has also been discovered that a large 5:1 sex ratio disparity is present in this species with adult males grossly outnumbering adult females (Swannack et al., 2007). Houston toads are active from late February through mid-April with their peak b(Swannack et al., 2007). The breeding activity is positively correlated with precipitation and is not continuous, usually occurring in several 3 to 5 day periods during the breeding season (Swannack et al., 2007). Males congregate at lentic ephemeral pools and shallow permanent bodies of water to attract females, and both adult males and females remain within about 200m of their breeding ponds (Swannack et al., 2007). Adult males can breed multiple times per year and return to the same breeding site every year (Jacobson, 1989). However, adult males and females reach sexual maturity at different times, with males beginning to reproduce during the breeding season after they are born and females maturing a year later (Quinn et al., 1984). This causes an intrinsic sex ratio disparity with adult males being more

numerous than adult females due to the delayed sexual maturity of females (Swannack et al., 2007). While causes of this disparity have been studied, models simulating the effect on population growth and dynamics have not been implicated. A higher ratio of males can lead to fast decreases in genetic variation within small populations, especially ones that live in fragmented habitats like the Houston toad (Swannack et al., 2007). Therefore it is critical to look at how this sex ratio disparity affects population dynamics of the Houston Toad and the use of stochastic modeling is a method of investigating this.

CHAPTER II

METHODS

A stochastic, age- and sex-structured population dynamics model was created in STELLA®7.0.1 for the purpose of studying the relationship between sex ratio disparity and population dynamics of the endangered Houston toad. State variables consisted of eggs and tadpoles (through 12 weeks of age), juveniles (13-39 weeks of age), 40-week-old juveniles, immature one-year-old females, mature two-year-old females, and mature males. Other variables in the model included mortality rates of each life stage, sex ratio of adult males to adult females, and sex-determination. The model was run for a duration of 520 weeks with a weekly time step.

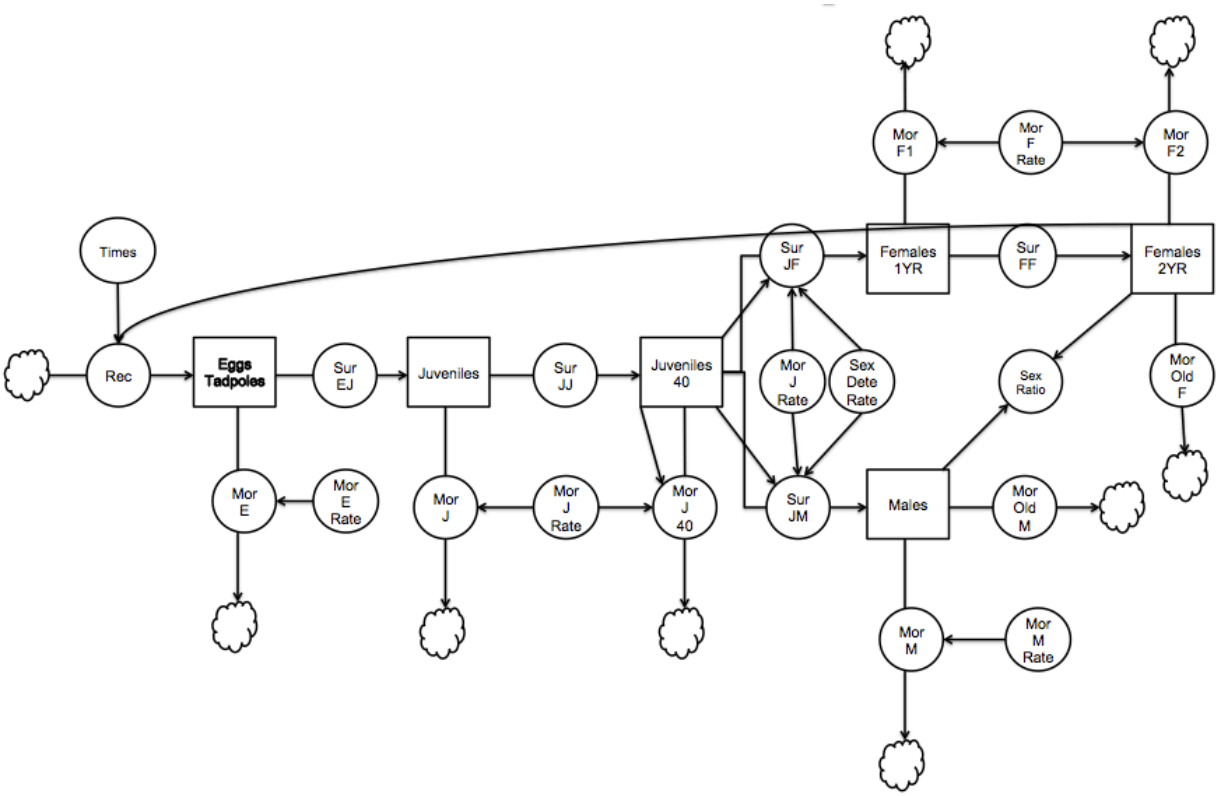

Figure 2. A conceptual model of the inflow and outflow to and from life stages of the Houston toad.

Initialization and parameters

Demographic data of 136 adult individuals gathered from the Griffith League Ranch in Bastrop, TX (Swanack et al., 2009) was used to initialize the model. Population parameters found in literature were used to initialize other variables in the model. The survival rate of tadpoles through the first 12 weeks of life was reported to be 0.05 (Swanack et al., 2009); therefore the initial and constant mortality rate used in the simulations was 0.95. Since a range of survival was not provided in literature, a range of 0.93-0.97 was used for the egg and tadpole mortality rate simulations. Juvenile survival was discovered to be between 0.0075 and 0.015 annually (Swanack et al., 2009); therefore a mortality rate range of 0.985 to 0.9925 was used for

simulations. The mortality rate of 0.985 was used as the initial and constant parameter for simulations where the juvenile mortality rate was held constant. Male survival was most recently reported to be either 0.15 or 0.27 (Swanack et al., 2009). Thus the male mortality rate range of 0.73 to 0.85 was used for simulations and the mortality rate of 0.73 was used when male mortality rate was held constant. A rate of 0.20 has been published as the adult female survival rate (Hatfield, 2004). Since data was not found to suggest a possible range of adult female mortality rates, the range of 0.75 to 0.85 was used for simulations. The rate of 0.80 was used when adult mortality rate was held constant. After selecting the parameters for the model, the rates found in literature were converted into weekly rates using a set of equations to fit the model since the toad life stages are based on weeks.

$$S = 1 - (1 - L)^{1/t}$$

Equation 1. Conversion for rates that decrease a state variable (e.g., mortality rates)

$$L = 1 - (1 - S)^{t}$$

Equation 2. Conversion for rates that increase a state variable (e.g., growth rates)

Where S equals the rate at the smaller time step, L is the rate at the larger time step, and t is the number of smaller time steps within the larger time step.

Simulations 1-41 in STELLA®7.0.1

The experiment was set up with a total of 41 simulations to be run using the model created in STELLA®7.0.1. The first simulation that was run consisted of the initial parameters that were used when mortality rates were held constant. Simulations 2-11 tested the range of adult male mortality rates, simulations 12-21 tested varying adult female mortality rate, simulations 22-31 tested varying juvenile mortality rate, and simulations 32-41 tested varying egg and tadpole mortality rate.

Simulations 42-82 in STELLA®7.0.1

An additional set of 41 simulations were run in order to determine mortality rates for each life stage in which the sex ratio disparity ranged from 1M:1F to 4M:1F to determine the effects on the adult population. Several simulations were run for each mortality rate. Simulations 43-53 tested ranges of adult male mortality rates, simulations 54-63 tested adult female mortality rates, simulations 64-73 tested juvenile mortality rates, and simulations 74-84 tested egg and tadpole mortality rates.

Best and worst scenario simulations in STELLA®7.0.1

Based on the results from the second set of simulations, the best and worst scenarios for each mortality rate will be determined and then simulated. The results will be graphed to display the survival of the population over 520 weeks.

CHAPTER III

RESULTS

Simulations 1-41

Based on the results from the first set of simulations, the current estimated mortality rate ranges from literature lead to the population crashing or reaching dangerously low numbers in ten years, as seen in Table A1 in the Appendix on page ## and in Figure 3 below.

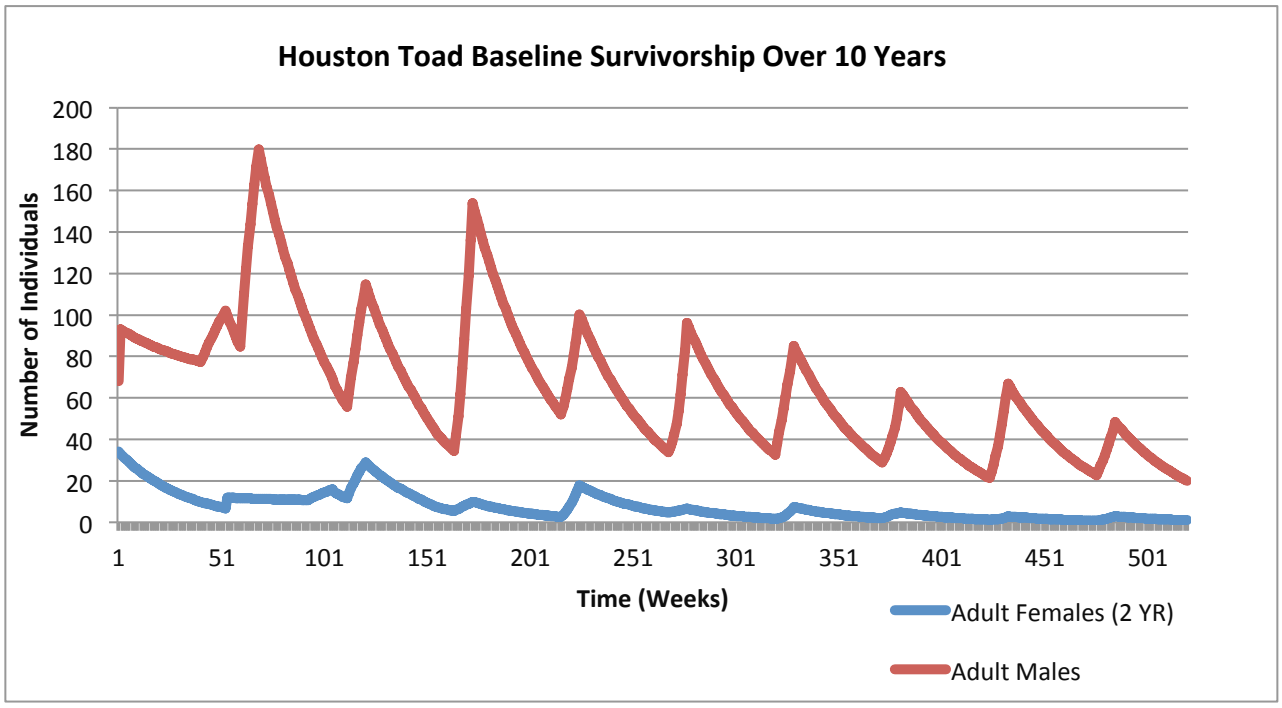

Figure 3. Graph of Simulation 1 using all baseline mortality rates.

The sex ratios with the corresponding simulations were all greater than 4M:1F except for simulations 10 and 11. As male mortality (MorM Rate) increased from the initial value of 0.024865, sex ratio decreased due to more males dying and the female mortality rate staying the

same. Simulations 10 and 11 had sex ratios less than 4M:1F, however the final population size was less than seven adult individuals. Sex ratio increased as the female mortality rate (MorF Rate) increased. This lead to a decreasing population due to a smaller number of females surviving to reproduce and in turn not as many eggs and tadpoles surviving to adulthood. Increasing juvenile mortality rate (MorJ Rate) lead to lower sex ratio disparity but also lower final population sizes. The same was observed with increasing egg and tadpole mortality (MorE Rate). All of these trends are displayed below in Figure 4.

Life Stage	Mortality Rate	Sex Ratio	Population
Eggs/Tadpoles	Decreased	Increased	Grew
Juveniles	Decreased	Increased	Grew
Adult Females	Decreased	Decreased	Grew
Adult Males	Decreased	Increased	Grew

Figure 4. Table showing the relationship between population growth, mortality rate, and sex ratio for each life stage.

Simulations 42-82

An additional set of simulations were run due to the failure of the first set to sustain the Houston toad population after ten years. The goal of this set was to identify which mortality rates fell under a sustainable range of sex ratio disparities, 1M:1F to 4M:1F, with 4M:1F being the point at which the sex ratio disparity is unsustainable. Sex ratios have been determined to be

evolutionarily sustainable at 1M:1F (Gibbons, 1990), which is what Houston toads emerge at. Based on the results in Table A2, the survival of the population is mostly dependent upon female survival, as more females are needed to increase the number of eggs laid and consequently higher probability of more juveniles surviving to adulthood.

Best and worst scenario for simulations 42-82

After simulations 42-82 were run in STELLA®7.0.1, the mortality rates for each life stage that corresponded with sex ratios of 1M:1F were chosen. However, mortality rates that corresponded with sex ratios of less than 4M:1F could not be calculated for the Egg/Tadpole and Juvenile life stages. This resulted in using baseline numbers for eggs/tadpoles and juveniles, and weekly mortality rates of 0.0555 for males and 0.0056 for females. The resulting graph, displayed below in Figure 5, leads to exponential growth.

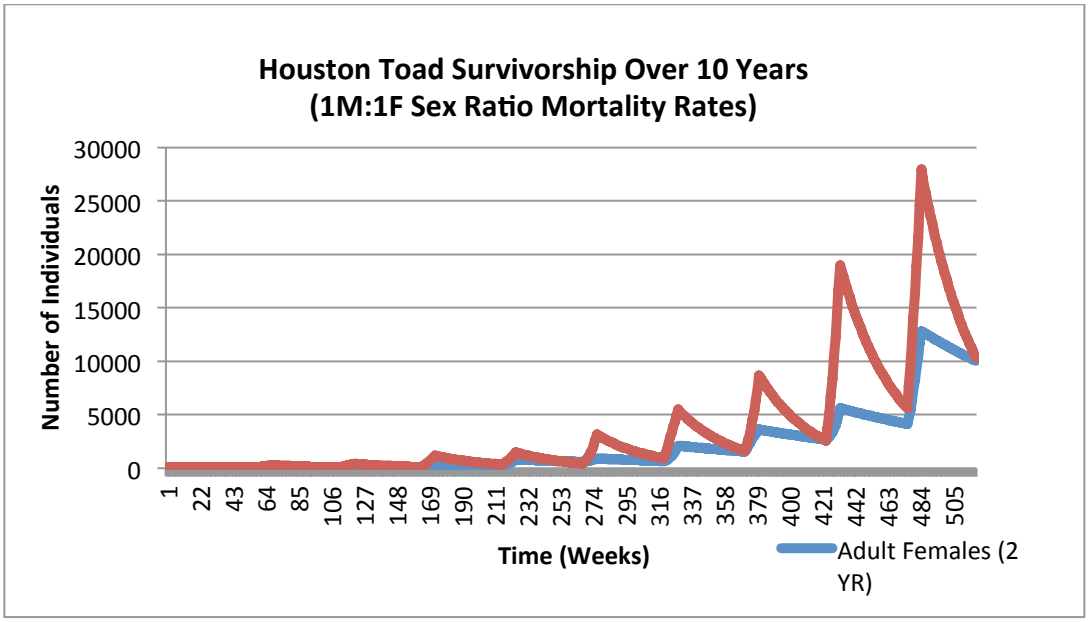

Figure 5. Best scenario using mortality rates from simulations 42-82 that corresponded with a final sex ratio of 1M:1F.

The worst scenario was also run using mortality rates that corresponded with final sex ratios of 4M:1F. The weekly mortality rates used for this simulation included 0.0279 for males, 0.0279 for females, 0.128 for juveniles, and 0.291 for eggs/tadpoles. An exponentially decreasing slope was the result of this simulation, as seen in Figure 6.

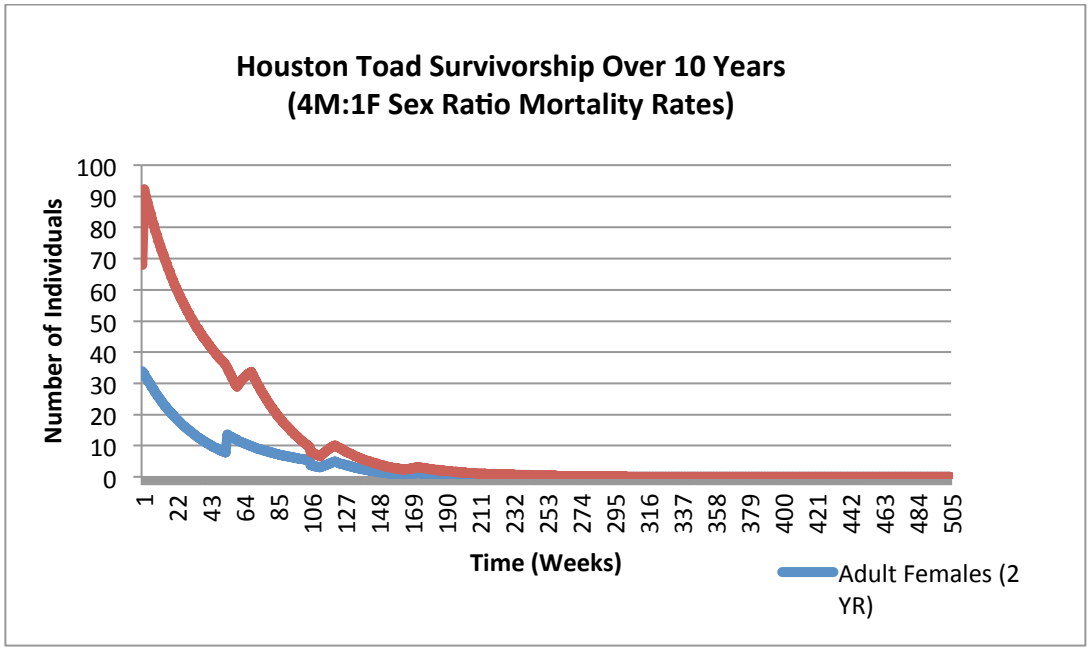

Figure 6. Worst scenario using mortality rates from simulations 42-82 that corresponded with a final sex ratio of 4M:1F.

CHAPTER IV

CONCLUSION

Based upon the results from the simulations completed in this study, it was determined that a sex ratio disparity greater than 4M:1F can lead to extirpation of subpopulations of the Houston toad if populations are low to begin with. Therefore, sex ratio disparity may be a contributing factor to the current decline of the Houston toad since their population levels are dangerously low due to primary threats that are mainly anthropogenic in nature. With current mortality rates, the Houston toad will be unlikely to survive past 10 years. Fortunately, the results in this study also showed that the Houston toad can recover greatly if juvenile and female survivorship is increased. This will also lead to an increasing sex ratio disparity as juvenile survivorship is increased due to the positive correlation between the two variables. However, this disparity will not be an issue as long as more juveniles are surviving to adulthood and thus supplying populations with more females and consequently higher chances of female survival to sexual maturity. In the future, I plan on expanding this research to examine the juvenile survivorship more closely to determine what range of values would result in a sustainable population. More studies focusing on the juvenile life stage in general are called for since not much is known about juvenile ecology of the Houston toad. Current conservation strategies and programs, especially those that involve the release of eggs and toadlets, would benefit immensely if reasons for the drastically high juvenile mortality rates were identified along with suggestions for minimizing those threats.

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APPENDIX A

Table A1. Simulations 1-41 that tested ranges of mortality rates based on literature.

Simulation	MorE Rate	MorJ Rate	MorF Rate	MorM Rate	Sex Ratio (Male/2yr Females)	2YR Females	Males	Total Final Adult Population
1	0.235276	0.0996688	0.030477	0.024865	6.04	1.47	8.87	10.34
2	0.235276	0.0996688	0.030477	0.0258	5.75	1.47	8.44	9.91
3	0.235276	0.0996688	0.030477	0.0268	5.45	1.47	8	9.47
4	0.235276	0.0996688	0.030477	0.0278	5.17	1.47	7.59	9.06
5	0.235276	0.0996688	0.030477	0.0288	4.91	1.47	7.21	8.68
6	0.235276	0.0996688	0.030477	0.0298	4.66	1.47	6.84	8.31
7	0.235276	0.0996688	0.030477	0.0308	4.43	1.47	6.5	7.97
8	0.235276	0.0996688	0.030477	0.0318	4.21	1.47	6.18	7.65
9	0.235276	0.0996688	0.030477	0.0328	4	1.47	5.88	7.35
10	0.235276	0.0996688	0.030477	0.0338	3.81	1.47	5.59	7.06
11	0.235276	0.0996688	0.030477	0.035826	3.45	1.47	5.06	6.53
12	0.235276	0.0996688	0.0263073	0.024865	4.59	5.73	26.3	32.03
13	0.235276	0.0996688	0.0273653	0.024865	4.92	4.06	19.96	24.02
14	0.235276	0.0996688	0.0284233	0.024865	5.27	2.87	15.15	18.02
15	0.235276	0.0996688	0.0294813	0.024865	5.66	2.03	11.5	13.53
16	0.235276	0.0996688	0.0305393	0.024865	6.07	1.44	6.07	7.51
17	0.235276	0.0996688	0.0315973	0.024865	6.51	1.02	6.63	7.65
18	0.235276	0.0996688	0.0326553	0.024865	6.99	0.72	5.04	5.76
19	0.235276	0.0996688	0.0337133	0.024865	7.51	0.51	3.83	4.34
20	0.235276	0.0996688	0.0347713	0.024865	8.07	0.36	2.91	3.27
21	0.235276	0.0996688	0.0358256	0.024865	8.67	0.26	2.21	2.47

Table A1 (Continued).

22	0.235276	0.101389	0.030477	0.024865	5.95	1.09	6.49	7.58
23	0.235276	0.103109	0.030477	0.024865	5.86	0.81	4.75	5.56
24	0.235276	0.104829	0.030477	0.024865	5.77	0.6	3.47	4.07
25	0.235276	0.106549	0.030477	0.024865	5.69	0.45	2.54	2.99
26	0.235276	0.108269	0.030477	0.024865	5.6	0.33	1.86	2.19
27	0.235276	0.109989	0.030477	0.024865	5.52	0.25	1.36	1.61
28	0.235276	0.111709	0.030477	0.024865	5.43	0.18	0.99	1.17
29	0.235276	0.113429	0.030477	0.024865	5.35	0.14	0.73	0.87
30	0.235276	0.114349	0.030477	0.024865	5.3	0.12	0.61	0.73
31	0.235276	0.115136	0.030477	0.024865	5.27	0.1	0.53	0.63
32	0.198768	0.0996688	0.030477	0.024865	7.1	11.22	79.6	90.82
33	0.205598	0.0996688	0.030477	0.024865	6.9	7.69	53.07	60.76
34	0.212428	0.0996688	0.030477	0.024865	6.7	5.27	35.5	40.77
35	0.219258	0.0996688	0.030477	0.024865	6.51	3.6	23.43	27.03
36	0.226088	0.0996688	0.030477	0.024865	6.31	2.46	15.51	17.97
37	0.232918	0.0996688	0.030477	0.024865	6.11	1.68	10.25	11.93
38	0.239748	0.0996688	0.030477	0.024865	5.92	1.14	6.75	7.89
39	0.246578	0.0996688	0.030477	0.024865	5.72	0.78	4.44	5.22
40	0.25	0.0996688	0.030477	0.024865	5.62	0.64	3.6	4.24
41	0.253391	0.0996688	0.030477	0.024865	5.53	0.53	2.92	3.45

Table A2. Simulations 42-82 that tested mortality rates resulting in sex ratios between 1 and 4.

Simulation	MorE Rate	MorJ Rate	MorF Rate	MorM Rate	Sex Ratio (Male/2yr Females)	2YR Females	Males	Total Final Adult Population
42	0.235276	0.0996688	0.030477	0.024865	6.04	1.47	8.87	10.34
43	0.235276	0.0996688	0.030477	0.0555	1	1	1	2
44	0.235276	0.0996688	0.030477	0.05243333	1.15	1	1.15	2.15
45	0.235276	0.0996688	0.030477	0.049732	1.31	1	1.31	2.31
46	0.235276	0.0996688	0.030477	0.04703067	1.49	1	1.48	2.48
47	0.235276	0.0996688	0.030477	0.04432934	1.7	1	1.69	2.69
48	0.235276	0.0996688	0.030477	0.04162801	1.91	1	1.93	2.93
49	0.235276	0.0996688	0.030477	0.03892668	2.22	1	2.21	3.21
50	0.235276	0.0996688	0.030477	0.03622535	2.55	1	2.54	3.54
51	0.235276	0.0996688	0.030477	0.03352402	2.94	1	2.93	3.93
52	0.235276	0.0996688	0.030477	0.03045735	3.47	1	3.47	4.47
53	0.235276	0.0996688	0.030477	0.0279	4	1	3.98	4.98
54	0.235276	0.0996688	0.0056	0.024865	1	2955.2	2956	5911.2
55	0.235276	0.0996688	0.008078	0.024865	1.16	1336.75	1550.34	2887.09
56	0.235276	0.0996688	0.010556	0.024865	1.35	604.38	813.56	1417.94
57	0.235276	0.0996688	0.013034	0.024865	1.56	273.11	427.23	700.34
58	0.235276	0.0996688	0.015512	0.024865	1.82	123.34	224.54	347.88
59	0.235276	0.0996688	0.01799	0.024865	2.12	55.66	118.13	173.79
60	0.235276	0.0996688	0.020468	0.024865	2.48	25.1	62.22	87.32
61	0.235276	0.0996688	0.022946	0.024865	2.9	11.31	32.82	44.13
62	0.235276	0.0996688	0.025424	0.024865	3.4	5.09	17.33	22.42

Table A2 (Continued).

63	0.235276	0.0996688	0.027902	0.024865	4	2.29	9.17	11.46
64	0.235276	*	0.030477	0.024865	*	*	*	*
65	0.235276	*	0.030477	0.024865	*	*	*	*
66	0.235276	*	0.030477	0.024865	*	*	*	*
67	0.235276	*	0.030477	0.024865	*	*	*	*
68	0.235276	*	0.030477	0.024865	*	*	*	*
69	0.235276	*	0.030477	0.024865	*	*	*	*
70	0.235276	*	0.030477	0.024865	*	*	*	*
71	0.235276	*	0.030477	0.024865	*	*	*	*
72	0.235276	*	0.030477	0.024865	*	*	*	*
73	0.235276	0.128	0.030477	0.024865	4	0.01	0.03	0.04
74	*	0.0996688	0.030477	0.024865	*		*	*
75	*	0.0996688	0.030477	0.024865	*	*	*	*
76	*	0.0996688	0.030477	0.024865	*	*	*	*
77	*	0.0996688	0.030477	0.024865	*	*	*	*
78	*	0.0996688	0.030477	0.024865	*	*	*	*
79	*	0.0996688	0.030477	0.024865	*	*	*	*

Table A2 (Continued).

80	*	0.0996688	0.030477	0.024865	*	*	*	*
81	*	0.0996688	0.030477	0.024865	*	*	*	*
82	0.291	0.0996688	0.030477	0.024865	4	0.03	0.14	0.17